Measuring and Expressing the Performance of Energy Storage Systems

DOE/OE Peer Review
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Purpose and Expected Outcome

Purpose

- Develop duty cycles and metrics for 5 new applications
- Enhance existing protocol
- *Facilitate use of Protocol by SDOs and stakeholders*

Progress

- March 2012 – project initiated under DOE OE ESS Program to involve all interested stakeholders in the development of a protocol/pre-standard for immediate use and as a basis for US and international standards
- November 2012 – first version of the protocol completed (2 applications 7 performance metrics)
- June 2014 – second version completed (added 1 more application and enhanced selected provisions)
- April 2016 – third version completed (added 5 more applications, more metrics and revised format for ease of use)

Key Accomplishments

- Five new applications
- Released version 2 of the Protocol
  - http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22010Rev2.pdf
  - http://www.sandia.gov/ess/sandia-national-laboratories-publications/
  - Most duty cycles embedded in the pdf as Excel sheets
    - http://www.sandia.gov/ess/publications/SAND2013-7315P.xlsx
    - http://www.sandia.gov/ess/publications/SAND2016-2543R.xlsx
    - http://www.sandia.gov/ess/publications/SAND2016-2544R.xlsx
- Held webinar hosted by CESA on June 30
  - http://cesa.org/webinars/measuring-energy-storage-system-performance/ (PNNL-SA-118995/SAND2016-6155 PE)
  - 457 registrations from 354 organizations, 206 attendees
- Released Webinar Questions and Answers (PNNL-25540/SAND2016-6668 O)
- EPRI/ESIC and IEC TC120 incorporating this work

Applications Addressed

- Peak shaving
- Frequency regulation
- Islanded microgrids

Old

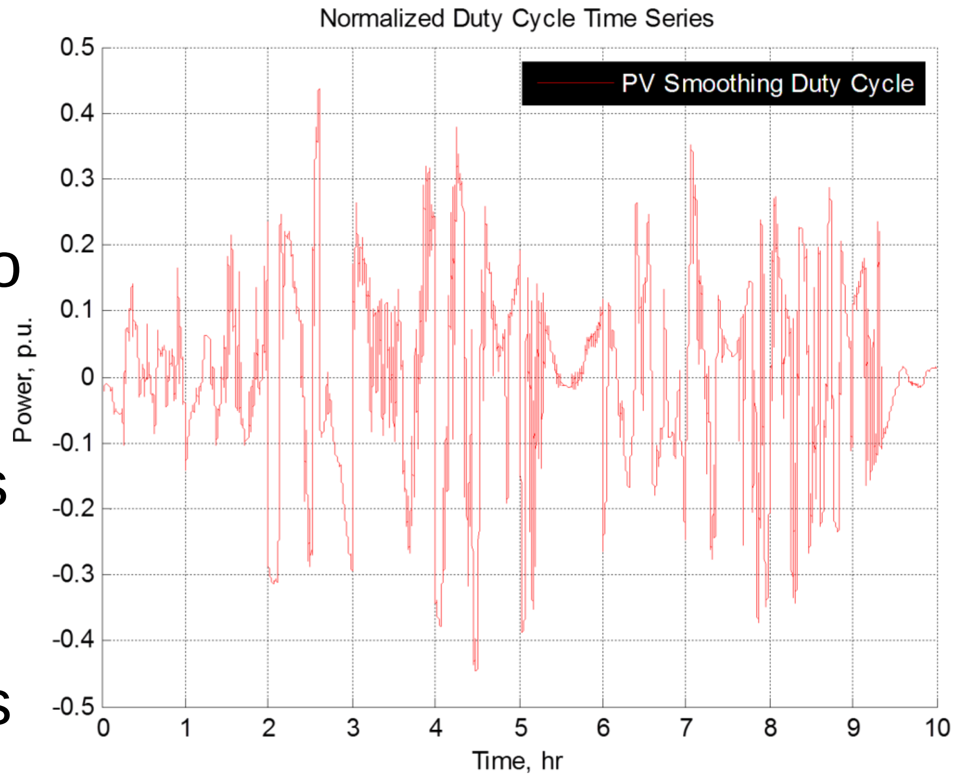
- Volt/var support
- Power quality (PQ)
- Frequency control (FC)
- PV Smoothing
- PV Firming

NEW

- Work for each new application
  - ✓ Describe and define the application
  - ✓ Develop appropriate duty cycle(s)
  - ✓ Confirm which existing metrics are applicable and if necessary adjust them for the application
  - ✓ Identify new metrics that are relevant and needed

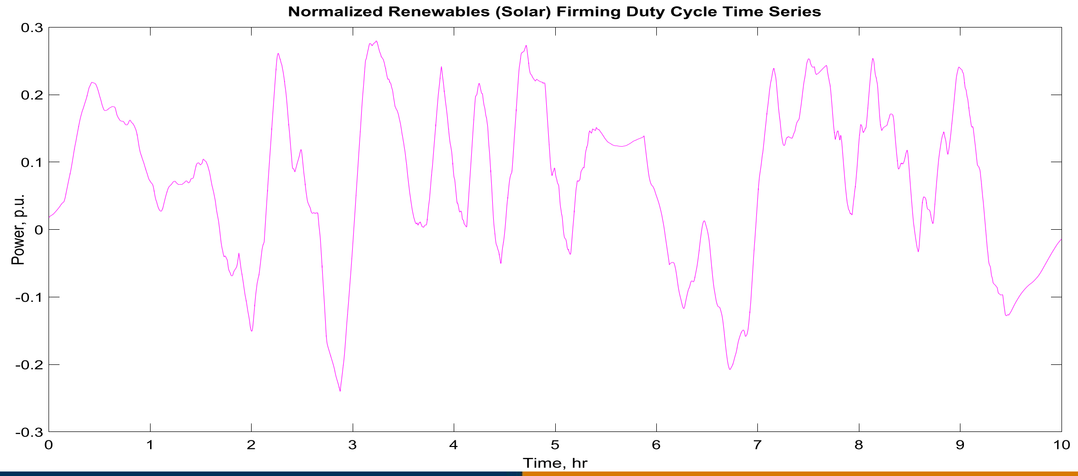
PV Smoothing

- ESS mitigates rapid fluctuations in PV power output that occur during periods with transient shadows on the PV array by adding power to or subtracting power from PV system output to smooth out the high frequency components of the PV power
- Reference performance metrics apply as they are ‘blind’ to application and duty-cycle
- Duty-cycle performance metrics apply with tests for each run using PV smoothing duty cycle



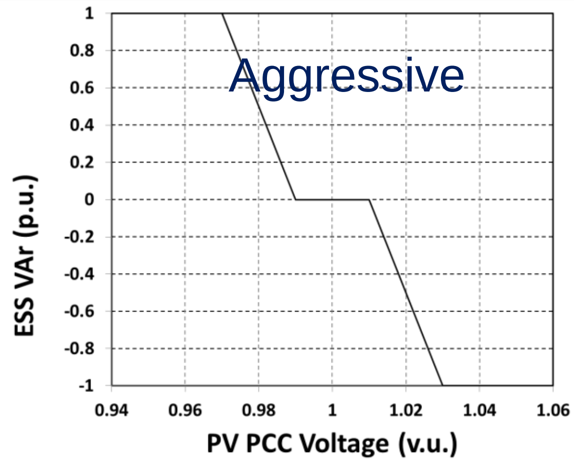
Renewables (PV) Firming

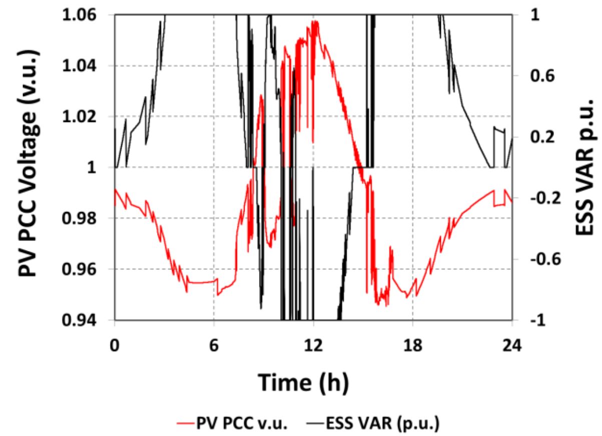
- ESS provides energy to supplement renewable (PV) generation so the combination of stored energy and renewable generation produces steady power output over a desired time window.
- Reference performance metrics apply as they are ‘blind’ to application and duty-cycle.
- Duty-cycle performance metrics apply with tests for each run using the renewables (PV) firming duty cycle.

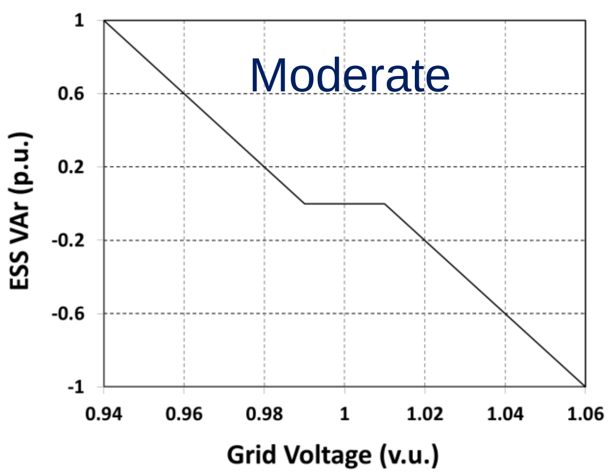


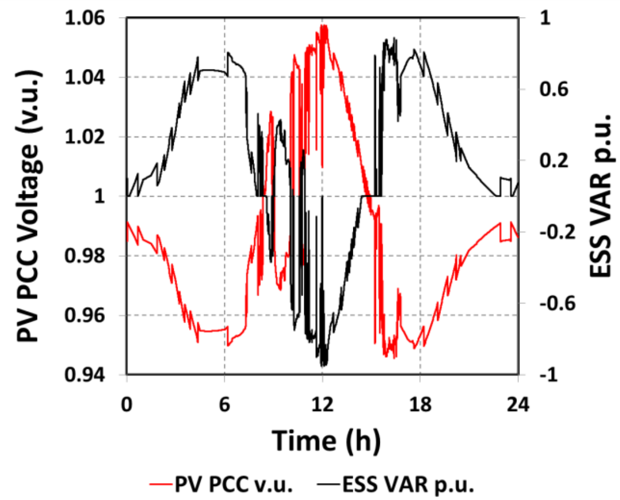
Volt-var summary ESS power as f(grid voltage)

- Developed for smart inverters (1), easily adapted for ESS
- PV farm at end of a 4 kW feeder
- Repeated for simulated grid voltage using GridLAB-D
- 24 hours continuous balancing signal





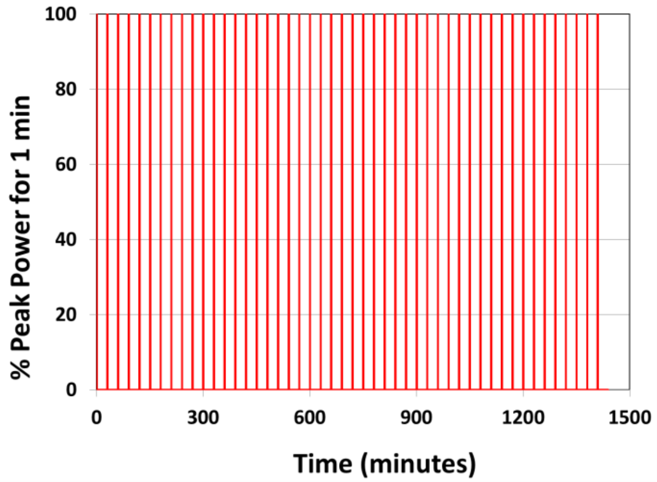


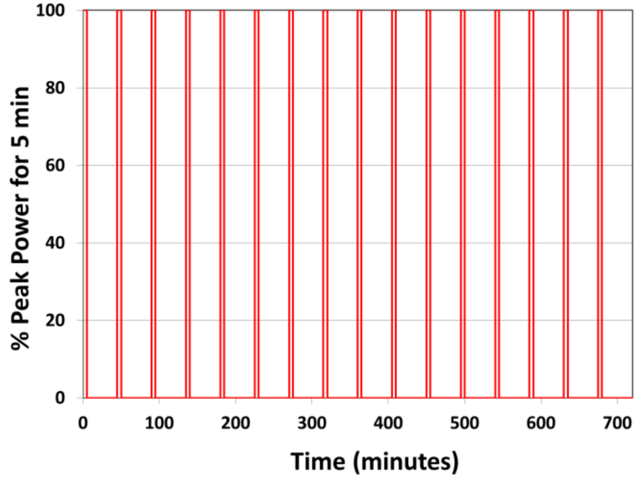


(1) Smart Inverter Working Group, SAND2013-9875, EPRI

Power Quality

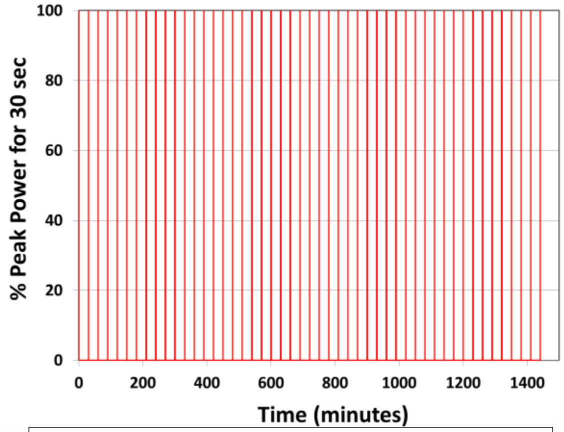
- ESS can mitigate a sag or interruption in voltage that can cause power disturbances that negatively impact power quality (mostly on distribution systems) by injecting real power for up to a few tens of seconds
- This application does not require storage to provide enough power for customers to ride through an outage w/o power loss
- The duty cycle consists of continuous discharge at peak power for 1 min, 5 min and 10 min, where peak power is defined as maximum power for 1 minute, 5 min and 10 min.

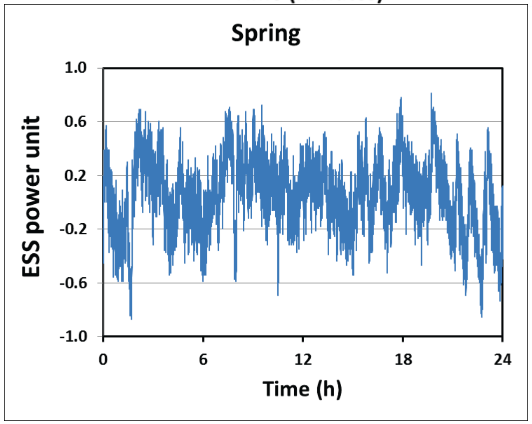




Primary and Secondary Frequency Control

- Sudden loss of generation – injection of real power
- Duty cycle (*charge for sudden loss of load*)
  - Discharge at 30-s peak power for 30 sec (primary frequency control)
  - Discharge at rated power for 20 min (secondary frequency control)
- Same approach used to charge ESS for sudden of load





- Primary frequency control (30-sec)
- Secondary frequency control - similar duty cycle for 20 min

- Dynamic frequency control – ESS response f(grid frequency) (1)
- Obtained grid frequency data from utility for 4 seasons

(1) ERDF/SAFT/Schneider Electric and others, Venteea 2 MW 1.3 MWh battery system, results presented by Bruno Prestat (EDF), Chair EPRI-ESIC WG4 Grid Integration. July 10, 2015

Duty-cycle New Metrics

Subject	Description
ΔSOC_Volt-VAr (Section 5.4.5.1)	The difference between the final and initial SOC shall be reported, along with the initial SOC
ΔSOC_active standby (Section 5.4.5.1)	The change in SOC at the end of an active standby of same duration as Volt-var duty cycle with auxiliary load turned on.
Wh_discharge (Section 5.4.5.1)	The real energy injected (with and without Volt-var duty cycle)
Wh_charge (Section 5.4.5.1)	The real energy absorbed (with and without Volt-var duty cycle)
Wh_net (Section 5.4.5.1)	The net energy (injected or absorbed) (with and without Volt-var duty cycle)
Peak Power (Section 5.4.5.2 for PQ, Section 5.4.5.3 for FC)	The peak power the ESS can provide for a specific duration.

Enhancements Related to Duty-cycle Performance

- Run duty-cycle tests in conjunction with reference performance tests
- Use same test set up and data gathering scheme – just run the duty-cycle tests using the duty-cycle for each intended ESS application
- For peak shaving tests the duty cycle may begin with charge OR discharge.
- Result tables for the peak shaving test specify maximum power and average power during charge and discharge
  - For charge, since charge duration is 12 hours, the charge power may taper at some point.
  - For discharge at various powers (6, 4, 2h), the power may taper off towards the end.

Reference Performance New Metrics

Subject	Description
Reactive Power Response Time (Section 5.2.3)	The time in seconds it takes ESS to reach 100 % rated apparent power during inductive and capacitive power from an initial state of rest.
Reactive Power Ramp Rate (Section 5.2.3)	The rate of change of reactive power delivered to (inductive) or absorbed by (capacitive) by an ESS over time expressed as MVAr per second.
Internal Resistance (Section 5.2.3)	The resistance to power flow of the ESS during charge and discharge
Standby Energy Loss Rate (Section 5.2.4)	Rate at which an energy storage system loses energy when it is in an activated state but not generating or absorbing power, including self-discharge rates and energy loss rates attributable to all other system components (i.e. BMS, EMS, and other auxiliary loads required for readiness of operation).
Self-discharge Rate (Section 5.2.5)	Rate at which an energy storage system loses energy when the storage medium is disconnected from all loads, except those required to prohibit it from entering into a state of permanent non-functionality.

Enhancements Related to Reference Performance

- In Rev. 1, the 1st cycle was excluded from cumulative RTE calculation. Included 1st cycle in Rev. 2
- In Rev 1, individual cycle RTE was excluded - it is now included
- Added separate equations for the case when auxiliary load is powered by a separate line (EPRI ESIC input)
- For capacity test, the test may begin with charge OR discharge
- Result tables for capacity test specify maximum power and average power during charge and discharge
  - This takes care of cases when power tapers towards he end of charge or discharge

Summary

- ✓ Revision 2 was released April 2016
- ✓ Revision 1 has been used as a basis for US and International (IEC TC 120) standards and is being applied by proponents and users of ESS
- ✓ Provided input to EPRI ESIC Performance WG
- ✓ Working with ASME and NEMA to adapt these findings
- ✓ Revision 2 adds key information and technical specifications, new applications, new metrics and significant formatting and use enhancements
- ✓ All proponents and users of ESS benefit when performance can be measured and expressed with confidence in a uniform, comparable and consistent manner

Acknowledgement

Dr. Imre Gyuk, DOE-Office of Electricity Delivery and Energy Reliability

U.S. DEPARTMENT OF ENERGY

All the participants of the working groups